

Row orientation effects on whole-canopy gas exchange of potted and field-grown grapevines

by

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S u m m a r y : The effects of canopy orientation (North-South vs. East-West) on total canopy assimilation (TCA) and transpiration (TCE) were evaluated on potted grapevines mounted on wheeled platforms for full swivel rotation. Eight vines were assembled in pairs to form four canopy walls 2 m long, 1.1 m tall and 0.25–0.30 m wide. TCA and TCE readings were also taken in the field on four NS-oriented, hedgerow cordon-trained grapevines. Diurnal trends of TCA recorded on potted vines showed little variability when related to row orientation. The TCE pattern for EW followed essentially that of light intensity, whereas a NS orientation induced a marked decrease in TCE at midday before recovering in mid-afternoon. As a result, water use efficiency (WUE) in NS rows was higher during the midday hours. Total canopy water loss in NS was linearly correlated with estimates of intercepted light, suggesting that water use was a function of both, light intensity and canopy geometry (i.e. more light lost to the ground at noon, hence less transpiration). The results for the NS-oriented field-grown canopies differed to some extent from those of the pot experiments. TCA showed a more marked afternoon decline and TCE flattened at noon, though with no apparent decrease. WUE efficiency was lowest at the highest evaporative demand. The daily water loss of field vines could not be predicted by total light interception estimates only, indicating a more complex regulation of canopy transpiration than recorded on potted plants.

Key words : row directions, whole-canopy gas exchange, assimilation, transpiration, total light interception, training systems.

Introduction

Row orientation is one of the factors accounting for the total amount of sunlight captured by a vineyard throughout the growing season. The incidence of row orientation on light interception and hence total vine dry matter production, however, varies according to canopy shape and height, latitude and time of year (SMART 1973; BALDINI and INTRIERI 1987). The effects induced by row orientation are in fact more pronounced for vertical, narrow canopies; they become negligible for more horizontal or flat canopies. In vertically, shoot-positioned hedgerow walls, a north-south (NS) orientation determines symmetrical light distribution over both sides of the vine and, at relatively low latitudes (less than 30° from the equator), also allows higher seasonal light interception than east-west (EW) oriented rows (SMART 1973). At such latitudes the EW orientation is inherently limiting since the diurnal sun's path tends to be parallel to the canopy, losing much light directly to the ground especially during the midday hours. The difference in the intercepted light between NS and EW oriented walls becomes less pronounced at higher latitudes where, due to the flatter solar track in the northern hemisphere, the sun keeps shining on the south side of an EW oriented row. The seasonal light interception by Sylvoz-trained rows calculated for 44°, 50° N has been found slightly higher in EW than in NS-oriented rows (MAGNANINI and INTRIERI 1987) regardless of maximum canopy height and interrow spacing (either 3 or 4 m). Others have found a higher light interception of NS rows at similar latitudes (44°, 40° N - Bordeaux) but closer row spacing (RIOU *et al.* 1989). A study conducted on spur-pruned cordon and free-cordon trained Chardonnay grapevines at the same lati-

tude has shown that the EW orientation reduced growth, yield and total dry matter per vine as compared to NS, NE-SW and NW-SE orientations but had no influence on total soluble solids (°Brix) and must pH in either system (INTRIERI *et al.* 1996).

Although the impact row orientation may have on both, quantity and distribution of light in a vineyard can be predicted by computer modeling once the basic inputs are provided (MAGNANINI 1985), it remains more troublesome to determine to what extent row orientation directly affects whole-canopy function. Although some models (PALMER 1989) are more flexible in terms of accepted inputs (varying leaf area densities or direct/diffuse light ratios), their predictions cannot include, for example, the variation in gas exchange which, in a NS-EW comparison, are related to the diurnal canopy illumination pattern (changing from the east to the west side of the row in NS, constantly hitting the south side in EW) and to variations in other microclimatic parameters (temperature and relative humidity). Recently, LEBON *et al.* (1995) have modelled row orientation effects on whole-vine canopy gas exchange, yet found only small differences between NS and EW independent of the season.

The major drawbacks for studies of this type are thus the need to monitor the physiological response of experimental units (*i.e.* a whole canopy) large enough to include the effects produced by different row orientations and the possibility of carrying out either high-frequency or continuous readings to take into account diurnal effects. The availability of relatively simple, custom-built transportable whole-vine gas exchange systems (CORELLI-GRAPPADELLI and MAGNANINI 1993; PONI *et al.* 1997) has now made this kind of investigation more feasible. The present survey was under-

taken to assess the effect of row orientation (NS and EW) on the diurnal gas exchange pattern of potted grapevine canopies. In a separate field study we analyzed the diurnal gas exchange pattern of NS-oriented hedgerow canopies.

Material and methods

Gas exchange system: The gas exchange system to measure total canopy assimilation (TCA) and total canopy transpiration (TCE) includes air-fed centrifugal blowers for high flow rates, 4 flexible, transparent polyethylene chambers enclosing the entire canopy, a portable infrared gas analyzer and a data logger for system programming, data storing and processing. Details are reported by PONI *et al.* (1997).

Pot study: Eight, 4-year-old ownrooted Chardonnay grapevines grown outdoors in 120 l pots containing a substrate of peat, sand and soil (2.5:1.5:1) were used. In winter 1996 all the vines were pruned to about 15 two-node spurs on a 1 m long, permanent horizontal cordon-trained 1 m above the ground. This bud load resulted in about 22 canes per vine of low-to-moderate vigour counted at the end of the season. At budbreak the vines were grouped into 4 pairs, each of two adjacent pots, and loaded on wheeled platforms to enable full swivel in all directions (Fig. 1). Each vine pair was framed by stakes and wires to form a canopy wall of about 2 m in length and about 1.1 m in height above the cordon. Budbreak occurred in mid-March and shoot growth was directed upwards by shoot positioning and tying until the end of June, when most of the shoot tips yellowed indicating growth cessation. At that stage the average depth of the canopies was about 25-30 cm. Since the crop level varied distinctly among vines, all vine clusters were removed at pre-bloom and plants were watered daily to pot water capacity throughout the trial. All pots were painted white and then wrapped in light colored cloths to limit root overheating.

The gas exchange system started operating mid-June on the 4 two-vine replicates. Air flow was adjusted to about 15 l s^{-1} whereas the volume of the elliptical chambers varied from 6 to 7 m^3 . The measurements were performed in the following 4 combinations: all canopies at NS, canopies

1 and 4 at EW and canopies 2 and 3 at NS, all canopies at EW, canopies 2 and 3 at EW and canopies 1 and 4 at NS. This layout was chosen to enable better control of both environmental and vine-to-vine variability in that, according to a given combination, gas exchange of NS and EW canopies could be measured on the same day and related to each individual vine. The pots were spaced to avoid as much as possible mutual shading among canopies within each orientation pattern. The system was allowed to operate continuously on each combination for about 4-7 d, although no data were logged for the fourth combination (canopies 2, 3 at EW and canopies 1, 4 at NS) due to adverse weather conditions.

On June 13, with the canopies arranged in the second combination, the chambers were temporarily removed to perform total light interception measurements. The fraction of light intercepted by each canopy was estimated by taking below-canopy photosynthetic flux density (PFD) readings with a specially designed line sensor equipped with 16 cosine-corrected PFD sensors, 7 cm spacing, and linked to a CR10 Campbell data logger. The line sensor was held perpendicular to the canopies and measurements were taken immediately below the cordon. The effective measuring length of the line (105 cm) was sufficient to capture the entire ground-projected canopy shadow regardless of measurement time. The line sensor was moved along the canopy and data were recorded every 20 cm to get 10 scans per canopy yielding a total of 160 individual light values. The light readings were recorded three times during the day, 2 h before noon, at noon and 2 h after noon for the two NS oriented canopies; the light measurements were taken only at noon in the EW-oriented vines. Light interception (I) was calculated as $100 \text{ (total incoming light measured simultaneously above the canopies by an elevated PFD sensor) minus the calculated fractional light transmission underneath the canopies (\%T)}$.

A sample of 40 main and lateral leaves per canopy was taken at the end of measurements (mid-July) and the area of each leaf was measured with a LI-COR 3000 meter. At leaf fall, all main and lateral nodes of each vine were counted and total leaf area per vine was estimated on the basis of total node counts and average leaf area of each leaf type (main and lateral).

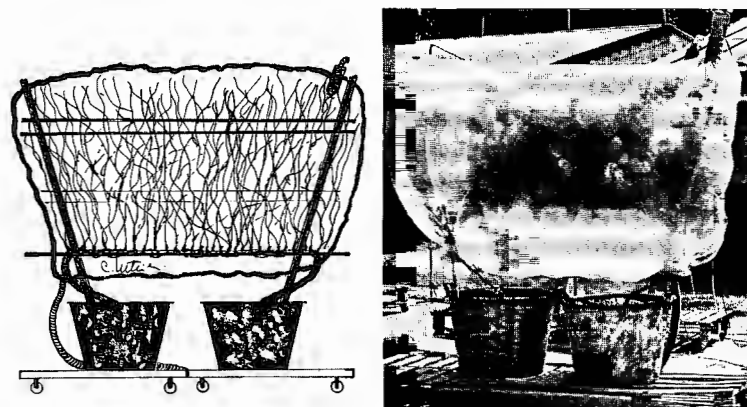


Fig. 1: Canopy structure of a pair of spur-pruned vines used as a single canopy in pot studies (left). One of the 4 vine pairs during gas exchange measurements (right).

Field study: The whole-vine gas exchange measurements were taken in a specially designed vineyard where rows planted at different orientations (NS, EW, NE-SW, NW-SE) were available (INTRIERI *et al.* 1996). The measurements were carried out on 4, vertically shoot-positioned, spur-pruned cordon (SPC) trained vines on two adjacent NS oriented rows spaced 2.5 m apart (Fig. 2). These were the central rows of a block of 4. Intrarow vine spacing was 1.5 m and bud load was 12-15 nodes per meter of cordon length. The SPC shoot growth was directed upward by paired catch wires set at 35 and 80 cm above the cordon, which was 1.2 m above the ground. All the shoots growing above the top wires were topped at fruit set to limit the total canopy height at 1.2-1.3 m. The distance between wires was 30 cm for the bottom pair and 40 for the top one, thereby contributing to a slight widening of the canopy thickness from bottom to top.

The automated recording of gas exchange of these 4 NS oriented vines started on July 22 and continued for one week. The air flow rate to the system was increased to about 55-65 l·s⁻¹ (depending on vine size) to achieve better temperature control inside the chambers and to limit the inlet-outlet CO₂ differential to -25/-30 µl·l⁻¹ maximum. Upon completion of measurements a large sample of both main and lateral leaves (about 25 % of the estimated final total vine leaf area) was taken and the area of each leaf measured by a LI-COR 3000 meter. At leaf fall all the main and lateral nodes were counted and multiplied by the respective mean leaf area to estimate total leaf area per vine.

Single-leaf gas exchange was also measured on the NS-oriented vines at the beginning of August on a clear sunny day using a portable CIRAS system equipped with a 2.5 cm² leaf chamber and operating at a flow of 200 ml·min⁻¹. Five external main and lateral leaves on each side of each vine were tagged and measured from 9.30 to 11.30 a.m. and 1.30 to 3.30 p.m. This procedure was adopted to allow measurements on the same leaves which were mainly subjected either to direct or diffuse light depending upon the time of measurement. Assimilation (A) and transpiration (E) rates were then calculated according to LONG and HALLGREN (1985). Extrinsic water use efficiency (WUE) was calculated as the ratio of TCA to TCE. In parallel to gas exchange readings, the total light interception of two 10-m row length sections, including the vines formerly monitored for gas exchange, was estimated. The line sensor, identical to that used in the

pot study, was moved perpendicular to the row axis and scans were taken at a 25 cm spacing, yielding a total of 672 individual points. Time of measurements and methods used to calculate the intercepted light were as described above.

Results and Discussion

Pot study

Diurnal patterns of gas exchange: The daily courses of TCA and TCE measured on the 4 vines, all NS-oriented, are reported for a representative clear day along with that of PFD (Fig. 3, top left). Both, TCA and TCE increased rapidly in the morning with light intensity, reaching a maximum at ca. 9.00 a.m.. Thereafter mean TCA decreased slightly throughout the rest of the day, whereas TCE diminished temporarily around noon and recovered in the afternoon. Both TCA and TCE then began to decline almost simultaneously with incoming PFD, dropping below 500 µmol·m⁻²·s⁻¹. WUE showed an alternating pattern, the lowest values being recorded when TCE was highest, whereas the VPD peaked at mid-afternoon reaching values > 2 kPa (Fig. 3, bottom left).

Swiveling two of the 4 NS-oriented canopies to EW induced a marked change in the TCE trend, which became more bell-shaped with no apparent decrease during the midday hours (Fig. 4, top); the TCA patterns of the two orientations did not differ. The WUE trend for NS proved to be similar to that plotted two days before, whereas WUE in EW showed lowest values during the midday hours (Fig. 4, bottom). The sensitivity of TCE to canopy orientation was confirmed further by the gas exchange plots recorded on all EW-oriented canopies (Fig. 3, top right), showing that despite some short-term light fluctuations around noon, TCE essentially followed PFD whereas TCA was again rather constant throughout the day after peaking at mid-morning. WUE was inversely related to TCE reaching its minimum around noon when the water loss peaked (Fig. 3, bottom right).

The diurnal TCA and TCE trends reported in Figs. 3 and 4 indicate that these gas exchange parameters were affected differentially by canopy orientation. The amount of water transpired by the canopy of EW orientation was lin-

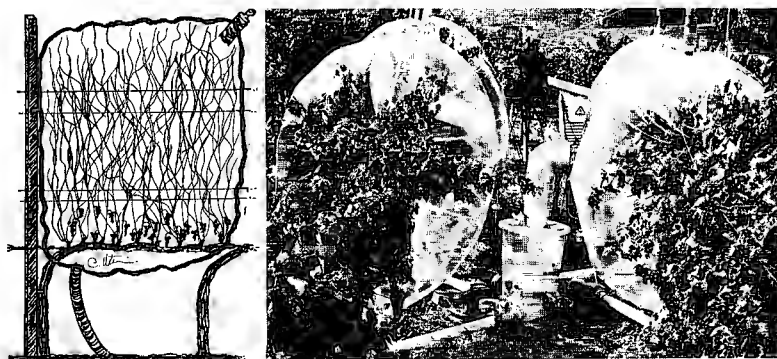


Fig. 2: Canopy structure of spur-pruned vines (each vine = one canopy) used in the field studies (left). Four vines monitored in two adjacent NS-oriented rows (right).

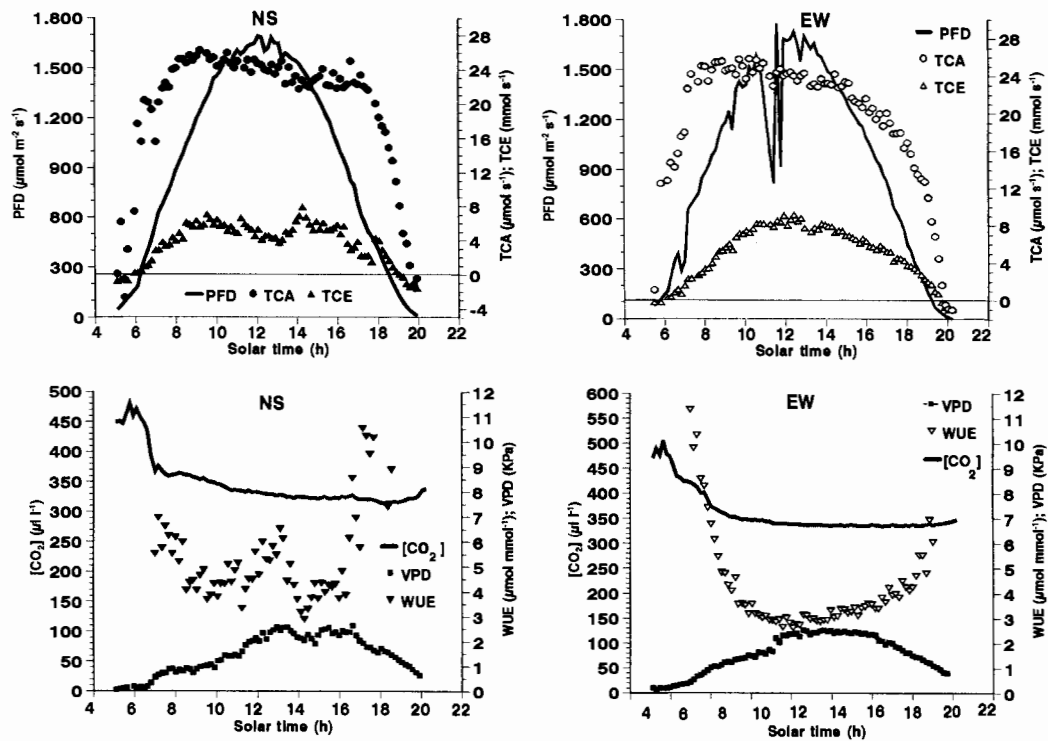


Fig. 3: Diurnal trends of PFD (—), TCA (●, ○) and TCE (▲, △) and of [CO₂] (—), VPD (■) and WUE (▼, ▽) monitored during clear days (June 7 and 15) on 4 chambered potted vines either NS- (left) or EW-oriented (right). Each point is the mean of 4 canopies; gas exchange data on a per vine basis.

early correlated to the intensity of incoming PFD measured above the canopy (Fig. 5). This result fits with the modeling outputs of daily light interception for a fully grown, vertical grapevine canopy at the same latitude and time of year indicating very little variation in the intercepted light (about 55–60%) from 9.00 a.m. to 5.00 p.m. (MAGNANINI and INTRIERI 1987). Furthermore, an assessment of the light available to the southern side of EW-oriented solid models reproducing, at the same latitude, a hedgerow height/row spacing ratio of 1:1, has shown that light intensity recorded at three canopy heights from the ground follows a normal distribution throughout the day regardless of the date of measurement (BALDINI and INTRIERI 1987). This suggests that under the conditions of the present trial the radiation load was the primary force driving transpiration of the EW-oriented canopies and that simple measurement of incoming radiation may be a viable way to predict the dynamics of daytime water loss.

Interestingly, the relationship between TCE and VPD of EW-oriented canopies calculated on a diurnal basis was not significant. This can also be inferred by comparing the TCE and VPD curves reported in Figs. 3 and 4. The VPD peaked at ca. 2.00–3.00 p.m. concurrently with the inlet temperature trend (not shown), but by that time TCE had already started to decline. This response implies that transpiration initially increases with the evaporative demand until decreasing stomatal conductance dominates over the still raising VPD, causing transpiration to diminish.

The regression between TCE and PFD calculated for the two NS-oriented vines also fits a polynomial model, show-

ing linearity up to $1200 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ and then a decline in TCE for $\text{PFD} > 1500 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ (Fig. 5). This discourages to use simple, above-canopy PFD readings as a predictor of water use in NS-oriented canopies and is mostly due to the discrepancy between the type of light measurements taken in this study (horizontal to the sun) and the light which actually hits a vertical canopy. As a matter of fact, readings taken by a horizontal sensor may be representative only for leaf blades close-to-parallel to the ground, while many other leaves are experiencing an array of largely differing light exposures (RIOU *et al.* 1989).

Thus, in a NS-oriented canopy with vertical shoots, the actual water loss seems to be more closely regulated by the interaction between sun position, canopy geometry and leaf distribution. In fact, TCE flattens and then declines at the highest midday PFDs (Fig. 5) when the total light intercepted by a narrow, NS-oriented hedgerow trellis is lowest due to a considerable fraction of the incoming light being directly lost to the ground (MAGNANINI and INTRIERI 1987). These assumptions are supported both by total light interception estimates, confirming higher light interception at intermediate sun angles rather than at zenith, and by a highly significant linear correlation between TCE and the percentage of light captured by the canopy (Fig. 6). Thus light interception, instead of a raw measurement of light intensity, should be preferred when trying to estimate the daily water use of a hedgerow, NS-oriented canopy at our latitude. VPD and TCE were not correlated, as was found for the EW orientation, thereby confirming, again, that the radiation load was the main driving force of water loss.

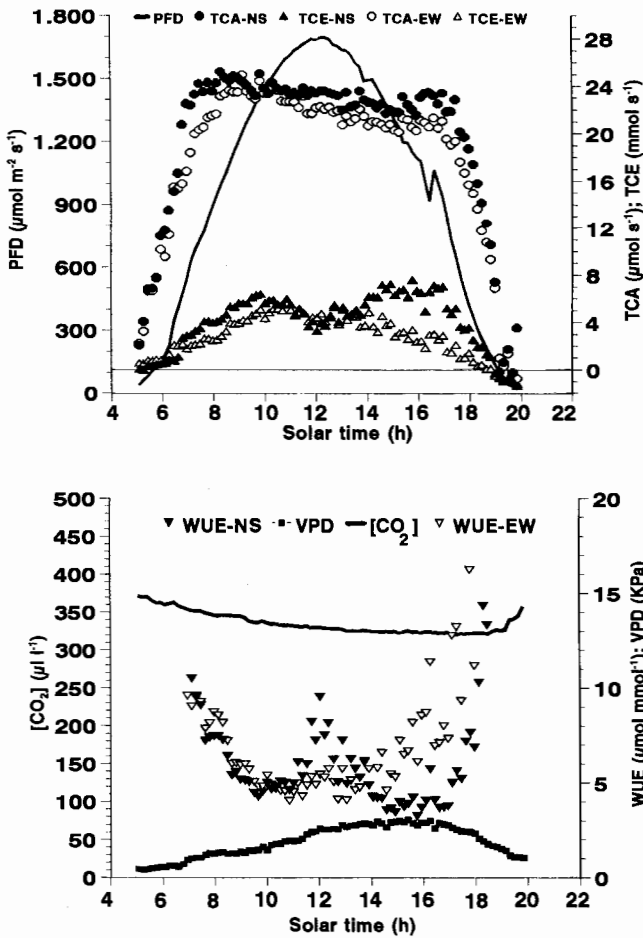


Fig. 4: Diurnal trends of PFD (—), TCA (● - NS; ○ - EW) and TCE (▲ - NS; △ - EW) and of $[\text{CO}_2]$ (—), VPD (■) and WUE (▼ - NS; ▽ - EW) of NS- and EW-oriented potted vines recorded on June 9. Each point is the mean of 2 canopies; gas exchange data on a per vine basis.

The diurnal pattern of TCA was not affected by canopy orientation, and the relationship TCA/PFD followed the well-known negative exponential model showing saturation at about 700-800 $\mu\text{mol m}^{-2} \text{s}^{-1}$ (not shown). When data collected the same day on both orientations are compared (Fig. 4, top), the TCA recorded for EW shows a slightly enhanced decline in the afternoon, which may relate to negative feedback effects on photosynthesis due to the long-term high light exposure of the leaves located at the southern side of the canopy (CORREIA *et al.* 1990). However, the maintenance of high TCA rates throughout the day in EW is consistent with the hypothesis that once the incoming PFD exceeds the saturation point of photosynthesis for the outer leaf layers, maximum assimilation rates are maintained during the day as long as light interception shows little variation. There is much evidence (SHAULIS *et al.* 1966; SMART 1985; WILLIAMS *et al.* 1987) that the outer leaf layers (*i.e.* the ones capturing most of the available radiation) may account for about 70-80 % of total vine assimilation.

Quite surprisingly, the diurnal TCA rate in NS was also constant (Fig. 4, top and Fig. 3, top left) despite the fact that around noon the light intercepted by those canopies decreased by 15-20 % as compared to morning and afternoon hours (Fig. 6). LEBON *et al.* (1995) found a clearly two-peaked

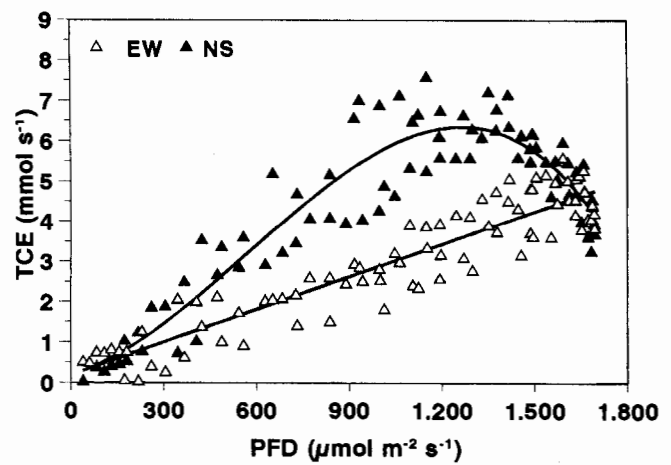


Fig. 5: Regression between TCE and PFD calculated from data recorded on June 9 on two NS- (▲) and two EW-oriented (△) potted vines. Polynomial regression equation for NS is: $y = 0.19 + 0.0022x + 8.04E - 0.6x^2 - 4.70E - 0.9x^3$; $R^2 = 0.87$. The linear regression equation for EW is: $y = 0.19 + 0.0027x$; $R^2 = 0.86$.

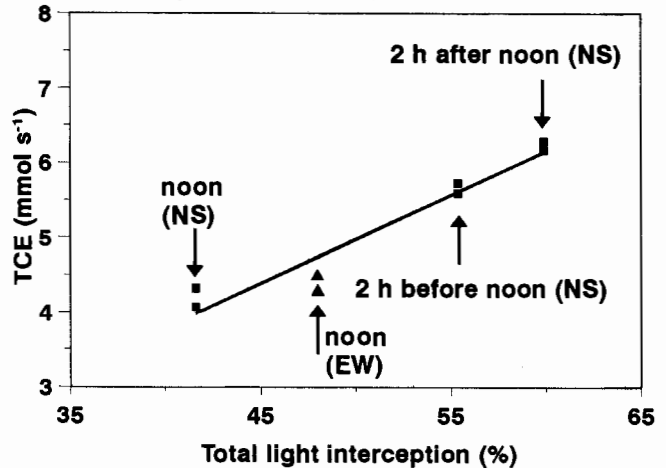


Fig. 6: Regression between TCE and total light interception calculated for NS- and EW-oriented potted vines. Light interception estimate available at noon only for EW. Each point represents the mean of two vines for June 9 and 10. TCE was synchronized with total light interception measurements by considering only data recorded in equivalent time windows. The linear regression equation is: $y = -0.927 + 0.118x$; $R^2 = 0.92$.

canopy assimilation rate in NS rows, similar to the diurnal pattern of light interception when using a model. A likely explanation for the mismatch between TCA and percent of intercepted light in our NS-oriented canopies would have to consider mainly the shape of the vines used in the present study. At high sun angles (close to zenith) direct radiation hits the top transversal section of the canopy and the photosynthetic contribution of the leaves located on both sides primarily relies upon the amount of diffuse radiation. Since our canopies had a rather low thickness (25-30 cm) the intensity of such diffuse light might have been enough to curtail photosynthesis to a limited extent. Furthermore, the mean total leaf area of each vine assembled in pairs varied from 3.4 to 4.8 m^2 , corresponding to a leaf area/exposed surface area ratio of 1.4-2.1 which is considered efficient for both light interception and distribution (SMART 1985). In addition sunflecks reaching the inside of the canopy may have

contributed to TCA at high sun angles thereby enhancing the photosynthetic performance of internal leaves (INTRIERI *et al.* 1995).

Effects of row orientation on mean TCA and TCE rates: Measuring the same vines under the two orientations during adjacent clear days enabled us to eliminate the interfering interaction between orientation of the canopy and amount and distribution of leaf area. Changing the orientation of the same canopies from NS to EW resulted, for TCA per unit leaf area (not shown), in either no or contrasting effects (slight increase or decrease for vines 1 and 4, respectively). In all cases, maximum TCA per unit leaf area was ca. $3 \mu\text{mol m}^{-2} \text{s}^{-1}$, a value consistently lower than those found in the field study. This difference may be related to either typical "pot effects" (e.g. root constriction) and lack of fruiting. The mean daily TCE was not affected by the orientation change except for vine 1, which exhibited a slight decrease. Overall, the mean daily rates of both parameters were hardly affected by canopy direction, suggesting that for TCE the daytime-related variation previously described had an offsetting effect.

Field study

Diurnal patterns of gas exchange: The daily mean trend of TCA and TCE calculated from readings concurrently taken on 4 NS-oriented, SPC-trained vines on a clear day showed a rapid increase of both parameters in the morning along with increasing PFD, leading to maximum rates between 9.30 and 10 a.m. (Fig. 7, top). TCA started to decline gradually till about 5 p.m.; thereafter the decrease became faster due to the concurrent diminishing PFD. By contrast, TCE remained essentially constant throughout most of the day before starting to decline at incoming PFD lower than $1000 \mu\text{mol m}^{-2} \text{s}^{-1}$. The same patterns were consistently found throughout another clear day (August 27, not shown). Since the mean vine leaf area of the SPC plants was 8.5 m^2 , maximum TCA and TCE rates per unit leaf area were about $6 \mu\text{mol m}^{-2} \text{s}^{-1}$ and $1.8 \text{ mmol m}^{-2} \text{s}^{-1}$, respectively.

The TCA and TCE trends reported in Fig. 7 (top) differ to some extent from those reported for the potted NS-oriented canopies. The TCA decline started earlier and was more pronounced under field conditions, which is in agreement with results reported for other fruit crops (FLORE and LAKSO 1991). The afternoon decline of CO_2 assimilation was also confirmed by the single-leaf readings, regardless of leaf type and light exposure at the time of measurement (Table). This rules out the possibility that the afternoon decline might have been related to unfavorable microclimate created by the plastic enclosures. Apparently stomata underwent a partial closure in the afternoon, since otherwise TCE would have increased with VPD, and TCA would have remained constant. The TCE trend in Fig. 7 (top) also differed from that reported for the potted canopies since no apparent temporary decrease of TCE around solar noon was observed. The diurnal pattern of TCE recorded in the field was somewhat intermediate between the one shown by the potted NS oriented walls and that of the same canopies turned EW.

The regression between TCE and PFD calculated for the NS-oriented field canopies again fits a polynomial model,

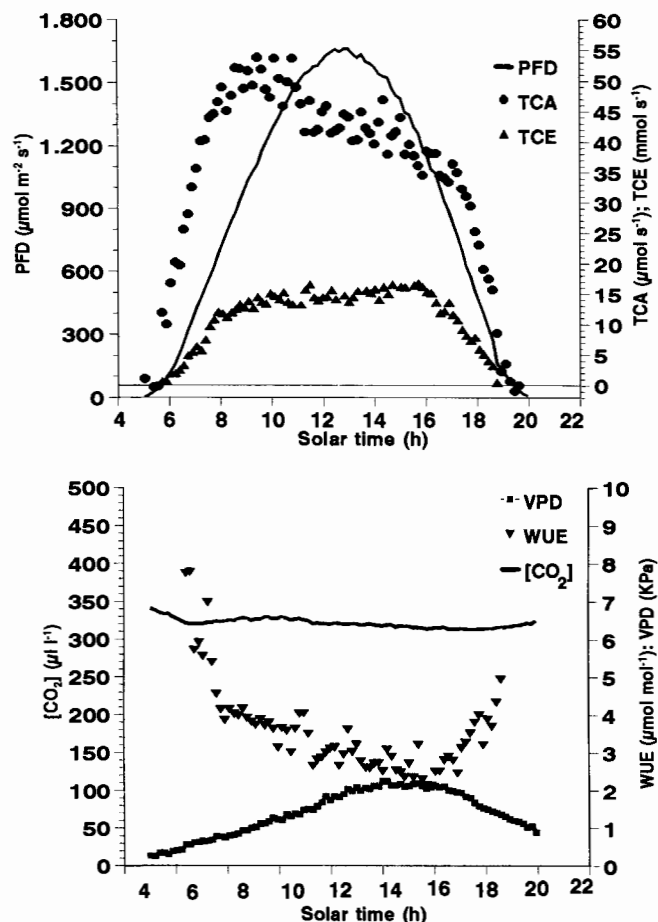


Fig. 7: Diurnal trends of PFD (—), TCA (●) and TCE (▲) and of $[\text{CO}_2]$ (—), VPD (■) and WUE (▼) of 4 chambered, NS-oriented SPC-trained field-grown vines during a clear day (July 23). Each point is the mean of 4 canopies; gas exchange data on a per vine basis.

showing linearity up to $1200 \mu\text{mol m}^{-2} \text{s}^{-1}$ and a saturation threshold thereafter (Fig. 8). The correlation between TCE and the percent of light intercepted by the canopies during the day was not significant (not shown) due to the mismatch between TCE and total light at noon (*i.e.* the former remained constant while the latter decreased by about 15 % as compared to the morning estimates). This suggests that the water loss at noon in the NS-oriented field-grown canopies was controlled by the interactions of several factors; water saving which would have resulted from a smaller canopy surface directly exposed to light at noon (46 % vs. 61 % and 59 % captured 2 h before and after noon) was offset by enhancing water loss possibly due to light intensity and VPD. The difference of the diurnal pattern of TCE reported in Fig. 7 (top) as compared to that found in the pot study (see Fig. 3, top left) should also take into account the absence of crop and the different root development in the potted vines. Hence, the daily water loss of the NS field canopies is not predictable on the basis of a single parameter, total intercepted light, PFD or VPD.

The daily WUE trend decreased gradually from early morning to mid-afternoon, when it reached the lowest values, only to recover again in late afternoon (Fig. 7, bottom). This pattern was inversely related to that for VPD, which

Table

Mean assimilation (A, $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$) and transpiration (E, $\text{mmol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$) rates (leaf area basis) recorded on single main and lateral leaves of the SPC-trained, NS-oriented vines at two different times during the day. Morning and afternoon readings were taken on the same leaves

Time of day	Main leaves				Lateral leaves			
	Light		Shade		Light		Shade	
	A	E	A	E	A	E	A	E
Morning (9.30-11.30)	11.9	2.8	2.7	1.9	11.5	2.9	3.0	1.5
Afternoon (13.30-15.30)	9.8	3.2	1.2	2.1	9.4	3.2	1.8	1.5
Sig. level of paired t-test	0.05	ns	0.01	ns	0.05	ns	0.01	ns

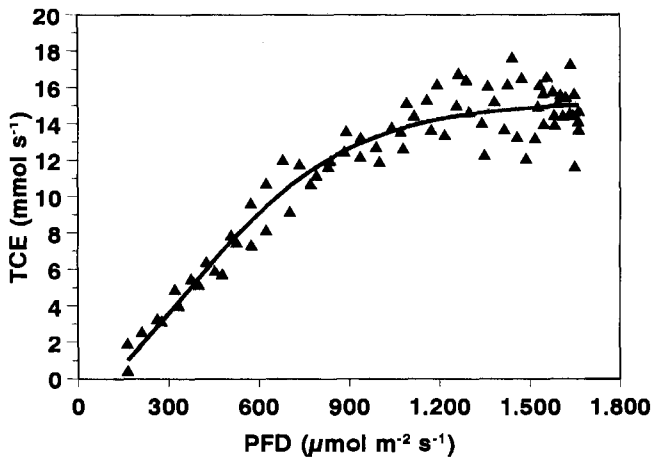


Fig. 8: Regression between TCE and PAR calculated for data recorded on July 23 on 4 NS-oriented field-grown vines. The non-linear regression equation is:

$$y = -2.82 + 17.96 / (1 + \exp(-(x - 44.0) / 246.6)); R^2 = 0.92.$$

peaked when WUE was lowest. The inference here is that at the highest evaporative demand TCA was more limited than TCE by stomatal closure.

Conclusions

The array of the data gathered on the effects of canopy orientation on assimilation and transpiration provides the basis for several practically-oriented considerations whose validity, however, is limited by the canopy types and the latitude of our study.

To find an analogy with a field training system, the canopies used in the pot experiment may be compared to a spur-pruned cordon established in a low-to-moderate vigor site at an inter-row spacing which rules out or minimizes the interaction between canopies of adjacent rows. Since the two orientations resulted to be rather similar in both, mean daily assimilation and water use, a choice between the two could be based either on practical needs (*i.e.* better use of the land or concerns of slope and erosion) or physiological aspects (*i.e.* a very thick canopy would not likely benefit from a EW orientation which would require a light distribu-

tion over both sides of the vine as that achievable with NS rows). However, our results show that, mostly due to the variable diurnal pattern of TCE, WUE would also change. A NS orientation would assure a higher WUE during the central part of the day when both, the VPD and the radiation load are high. If such environmental conditions are coupled with a shortage of soil water, NS rows may be helpful in reducing transpiration, which, in turn may prevent the leaf water potential dropping below the threshold values which cause stomatal closure and limit photosynthesis.

These considerations cannot be fully extended to the field results, which indicate that the vine response to a given orientation (*e.g.* NS) also depends on vine size, canopy density and growing conditions (pot vs. field). Under the conditions of the present study, a NS row orientation did not improve WUE during the central part of the day.

In the case of whole-canopy gas exchange surveys, a "re-thinking" of the most suitable type of light readings is necessary as well. These should be adapted to the specific canopy shape — a horizontal sensor would be appropriate for nearly flat canopy walls only, a round canopy would require a multi-directional sensor and a vertical trellis would benefit from measurements taken on all sides of the canopy coupled with estimates of daily light interception.

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